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USE OF CHEMICAL ADDITIVES TO IMPROVE AERATION RATES. STUDY OF MODELS OF AIR DISPERSERS

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Orono, Maine

1967

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Progress Report 3b

Use of Chemical Additives To Improve Aeration Rates

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STEFAN A. ZIEMINSKI

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U. S. Department
Of The Interior

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

Grant No. WP-00562-04

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PROGRESS REPORT NO. 3b

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Details of illustrations in
this document may be better
studied on microfiche.

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Abstract

The investigation presented in this report deals with a method for improving the rates of aeration. In order to achieve this objective, small quantities of some organic substances are introduced in the zone of bubble formation. These additives decrease bubble coalescence and improve the rate of transfer because of the substantial increase in the interfacial surface area. The tests were conducted with n-octanol, 4-methyl-2-pentanol and heptanoic acid. At a concentration of 1 ppm the n-octanol and 4-methyl-2-pentanol showed an improvement in the rate of aeration of 70 per cent over that in pure water. At a concentration of only 0.5 ppm n-octanol gave an improvement in the rate of transfer of 30 per cent. Since the design of the aerator and the agent were not optimized, it may be expected that still better effect could be obtained in a large scale installation.

Aeration is an important step in many industrial fermentation processes, in the treatment of sewage by bio-oxydation and, in recent times, it also has been used for supplying oxygen to streams polluted by oxidizable matter.

Contrary to most gas absorption processes we are dealing here with a material which is free and therefore no direct financial loss is incurred because of its incomplete absorption. However, the efficiency of aeration has a direct bearing on the air flow rate required to achieve a given performance, and thus on the energy requirement of the process. The cost of energy needed to compress and disperse the air is by far the most important item determining the economy of aeration systems.

At the optimum combination of these two energy items the efficiency of oxygen absorption varies between 10 and 20% in most activated sludge aerations. (1) In many cases the efficiency is much lower. The aeration tests conducted on the Flambeau River (Wisc.) offer a good example. (2) Using carborundum porous plates as air dispersers, the percent of oxygen absorbed was only 3.3 when the depth of immersion was 12 feet and the average dissolved oxygen concentration about 3 ppm (approximately 35% saturation). At this efficiency 145 cu. ft. of air must be compressed and dispersed to dissolve one cu. ft. of oxygen. This illustration shows how important is the energy requirement of this process. According to Wagner (3) this kind of installation requires about one Kw.hr for 1300 g of oxygen dissolved. Attempts to decrease energy requirements of the aeration processes resulted in the design of a number of air dispersing systems. They usually belong to one of the three main types of aeration units: diffused-air units in which air is injected into the liquid in the form of bubbles, mechanical aeration in which the air is dispersed by some kind of a rotary device, and the combination of these types.

In aeration of large bodies of water like rivers and streams, water turbines have been used to induce atmospheric air into water. (3, 8, 9, 10).

Downing (4) in England reviewing various air-dispersing systems comes to the conclusion that almost every conceivable idea for an aeration unit has been tried but the theoretical energy requirements at the maximum dissolved oxygen concentration gradient and 10°C. have all fallen within the relatively narrow range of 1500 to 3500 g of oxygen dissolved per one Kw.hr. Estimated practical values probably would be 20-25 per cent lower (5).

One of the authors of this paper (6, 7) has studied energy requirements of aerators in which the bubbles were produced by shear at the boundary of a rotating streamlined element. The lowest theoretical energy requirement of this system was one Kw.hr per 3800 g of oxygen dissolved. This performance was obtained at zero dissolved oxygen level, at room temperature, 12 feet immersion and assuming 100 per cent efficiency of the aerator drive and compressor. It is of interest to note that this performance corresponds closely to the upper limit as given by Downing (4).

There appears at present not much chance of any drastic improvement of the performance of aerators by changes in their mechanical design.

For an excellent review of recent publications in the field of gas-liquid contacting systems the reader is referred to the paper by Sideman et al. (11).

The objective of the present work was the improvement of the performance of air-water dispersers, however, by means of a different approach. The principle of this approach is to increase the rate of oxygen transfer by means of minute quantities of surface active substances which prevent bubble coalescence.

Pattle, R. E. (12, 13) comparing absorption efficiencies of various air dispersing systems noticed in some cases a marked increase of efficiency when 0.2% of acetic acid was added to water. The practical application of this action was suggested by Braasch and Braasch (14) who recommend the addition of 0.01% of lactic acid to the yeast wort to produce smaller bubbles and thus increase the mass transfer area. Carver (15) noticed that air bubbles produced in a Venturi diffuser gave higher rates of oxygen absorption than in pure water, despite reduced K_L values. This was due to the substantial increase in surface area afforded by smaller bubbles. Ju Chin Chu et al. (16) noticed a similar increase in extraction efficiency of a liquid-liquid system in the presence of a surface active agent.

One of the authors (S.A.Z.) conducted a comprehensive investigation of the effect of minute quantities of alcohols, mono- and dicarboxylic acids, and esters on the rate of oxygen transfer from air bubbles to water (17, 18, 19). A carborundum porous plate was used as a disperser. Figure 1 shows the results obtained with very dilute solutions of n-heptanoic acid. It can be seen that at very high dilutions the K_L first increases with concentration of the solute and then drops sharply below that for pure water. This behavior was a function of the chain length of the carboxylic acid, at least in the range from formic to heptanoic acids. The positions of the maxima in the initial parts of the curves shift progressively to lower concentrations with increase of the length of the carbon chain. It is also of interest to note the magnitude of this effect - e.g., in the case of heptanoic acid at a concentration of only 7.5 ppm. the value of the K_L increased by about 40%. The change in the instantaneous surface area (A) shows however a reversed trend. There is at first a small increase in the surface area which then increases

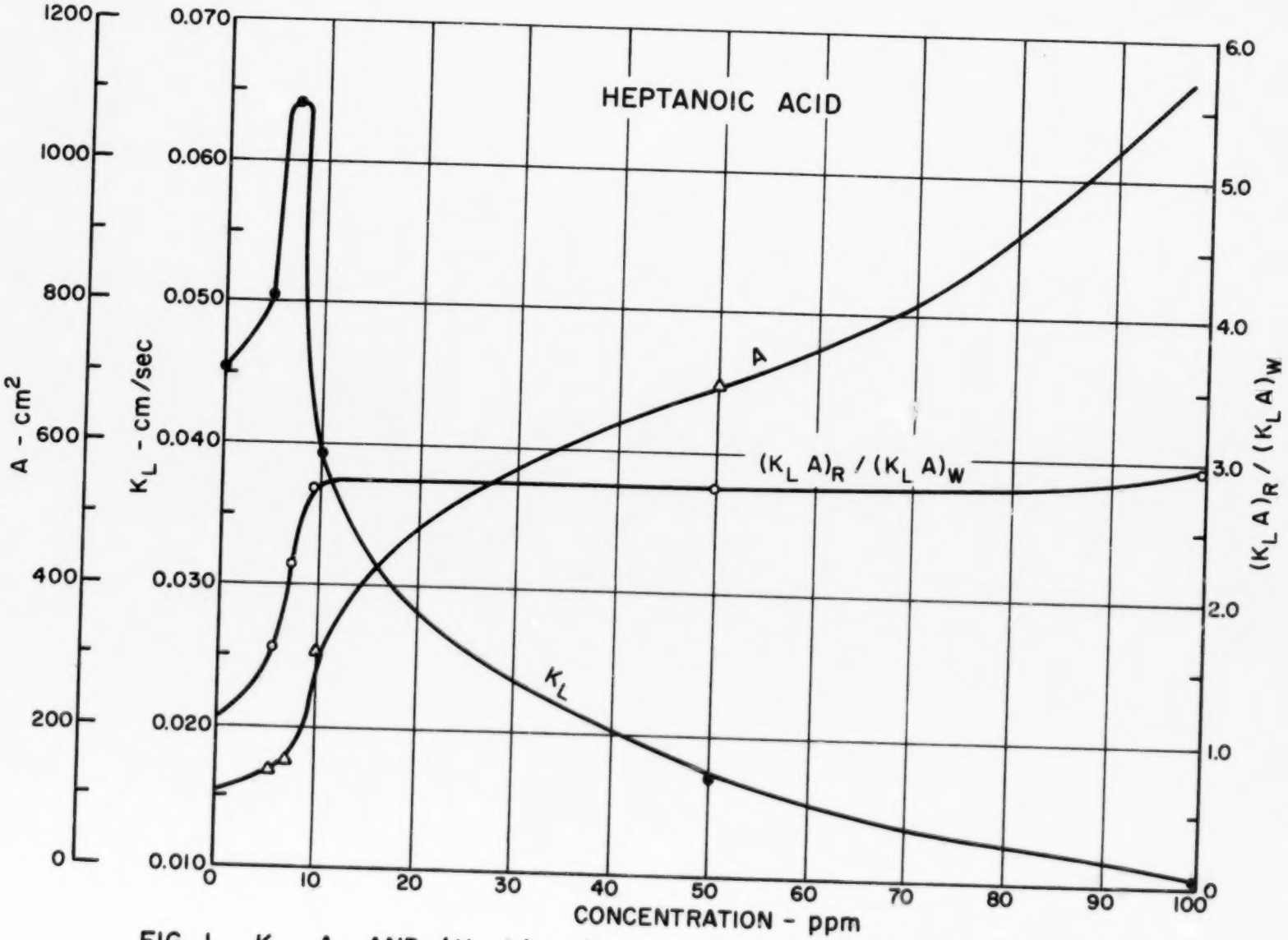

FIG. 1. K_L, A, AND $(K_L A)_R / (K_L A)_W$ VS. CONCENTRATION.

rapidly in the region of higher concentration. Because of the shapes of these curves the ratio of the total transfer rate in the solution $(K_L A)_R$ to that in water $(K_L A)_W$ first increases with concentration, reaching a maximum beyond which any further increase in concentration has no effect. The magnitude of this effect is considerable. At a concentration of only 10 ppm the efficiency of oxygen absorption increased by about 180% as compared with pure water. It must be emphasized that these effects depend not only on the agent and its concentration. They are to a great extent affected by the characteristics of the air dispersing system. On the whole it may be said that the greater the danger of bubble coalescence, the more effective is the agent in improving the transfer rate. Thus it is very effective in the case of a porous plate or a rotary aerator (17) but showed practically no effect in the case of a metal plate with fine perforations which were spaced 5 mm apart.

A more detailed discussion of the effects of small quantities of some organic substances on the interfacial area and mass transfer coefficient in air-water dispersions is given elsewhere (19).

A study of the air dispersing surface (porous plate) by means of short-exposure time photography showed that the effect of the solute on the interfacial surface area depends primarily on its concentration at the zone of bubble formation. The concentration in the bulk of the liquid is, in this respect, of less importance.

This behavior is understandable, if it is taken into account that the greatest danger of coalescence exists at the comparatively small zone where the bubbles are formed. Once they are dispersed in the bulk of the liquid, the chances of their coalescence are considerably less.

The main objective of this paper was to investigate a system in which the agent is introduced at the air dispersing surface immersed in a flowing

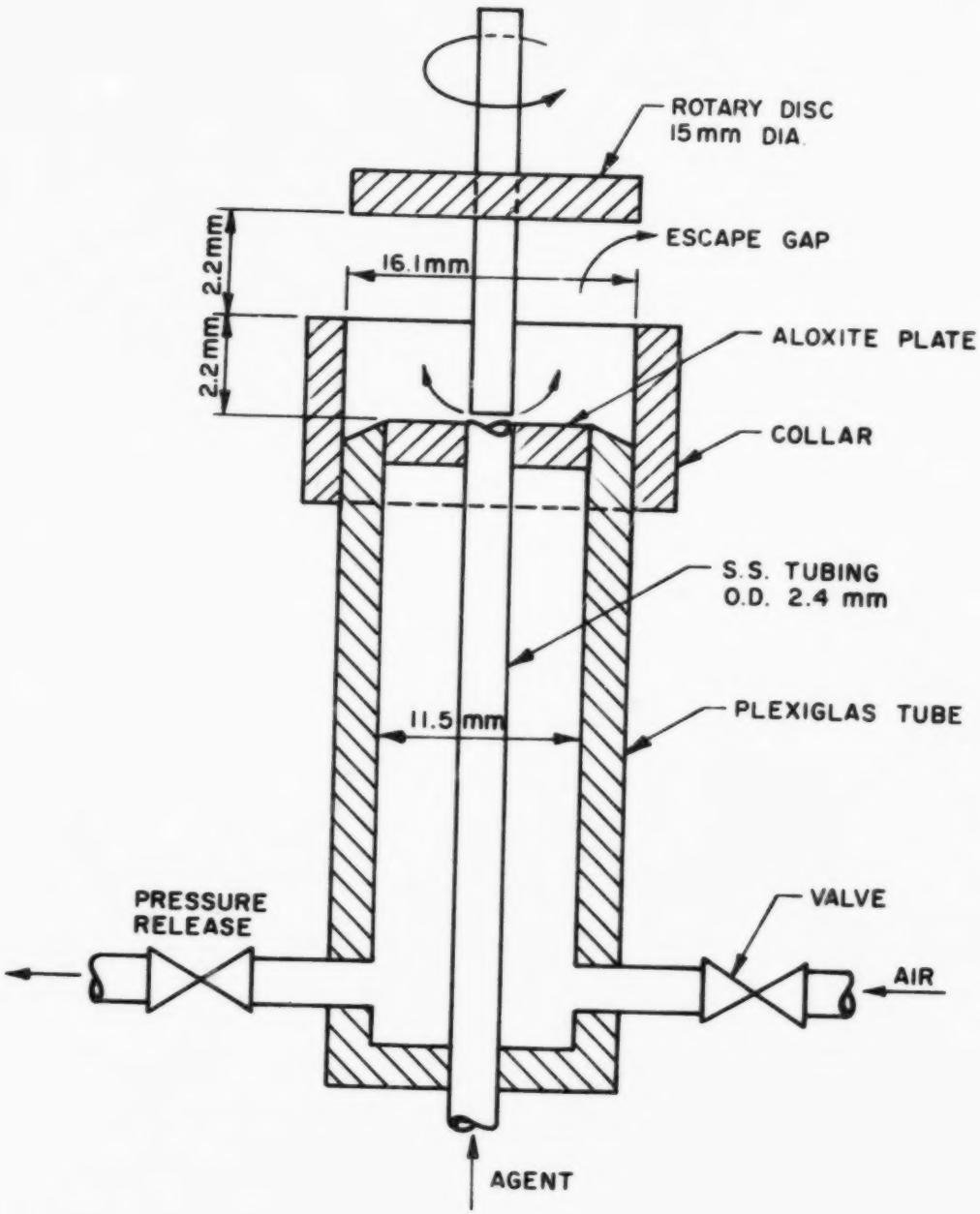

FIG. 2. AIR DISPERSER.

stream of water. In this way a zone of higher solute concentration is maintained at the vicinity of the aerator. It was not the purpose of this work to optimize the design or the type of the agent used, but to obtain an idea about the potential merits of the system and of the effects of some process variables.

The Design and Operation of the Aerator. One of the principal objectives of the design and operation of this aerator was to maintain a higher agent concentration at the air dispersing surface without much interference to the free motion of the bubbles. The result of such an interference would be increased coalescence.

The aerator (Fig. 2) consisted of an Aloxite porous plate, grade 1 (20) having a diameter of 0.984 cm. A hole was drilled in the middle of the plate to accommodate a stainless steel tubing 0.24 cm O.D. The plate was then cemented at the top of a plexiglas tube. The solution of the agent was introduced through the central tubing and the air through the annulus formed by the two tubings. Around the plate was mounted a plexiglas collar. Above the collar was installed a rotating disc leaving a gap of 2.2 mm between its lower surface and the top of the collar. The shaft of the disc extended down to the plate and terminated just above the central tubing. It helped to create a better distribution of the agent over the plate surface. The disc was driven by a variable speed motor through a flexible shaft. This arrangement made it possible to maintain a higher agent concentration in the collar. The mixture of bubbles and liquid was then thrown out through the gap between the collar and the disc by the centrifugal force of the latter. As was already mentioned the purpose of this work was not to arrive at some optimum design, but rather to evaluate the practical merits of the principle. E.g. a use of an inverted cone instead of the disc would facilitate the escape of air

bubbles and would probably improve the efficiency of the system. In addition to the air and solution inlets, the aerator was provided with a quick-opening pressure release valve. This valve was used for quick shutting off of the air flow when measuring the air holdup.

Figure 3 shows the aerator in normal operation except that a nigrosine solution was introduced instead of the agent. The photograph gives an idea of the changes in concentration of the solute in the vicinity of the disperser.

Fig. 3

TRACER PICTURE OF THE AERATOR IN OPERATION

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The Experimental Procedure

The study of operation of the aerator was conducted in a plexiglas absorption column 51 cm high and 12.5 cm in diameter (Fig. 4). One side of the column was removed and replaced with a flat sheet of plexiglas 8 cm wide. This was done to avoid optical distortion while photographing the bubbles. The aerator was mounted in the center of the bottom plate. Breathing air from a cylinder was introduced at a rate of 172 cc/min S.T.P. into the tube leading to the aerator. The column was operated continuously with well water of the following analysis:

Water Analysis

Component	ppm as $CaCO_3$
Calcium	26
Magnesium	18
Sodium	16
Hydroxide alkalinity	0
Carbonate "	0
Bicarbonate "	44
Chlorides	6
Sulfates	10
Free CO_2	11
Soluble silica	10
Iron	--
Chlorine	Neg.
Total Hardness	44
Conductivity (25°C)	91 micromhos
pH	6.9

Since the oxygen content of the water was well below 1 ppm, it was introduced directly into the column without previous deoxygenation. The agent solution was passed through a flowmeter into the disperser. The total combined flow of water and agent solution was 500 cc/min in all tests. In order to prevent surface areation, the column was covered with a plexiglas plate. At 20 and 30 minutes from the time the water filled the column samples were taken from the top and bottom sampling tubes for dissolved oxygen (D.O.) determination. This was done to check if the steady state had been reached. Because of the vigorous circulation induced

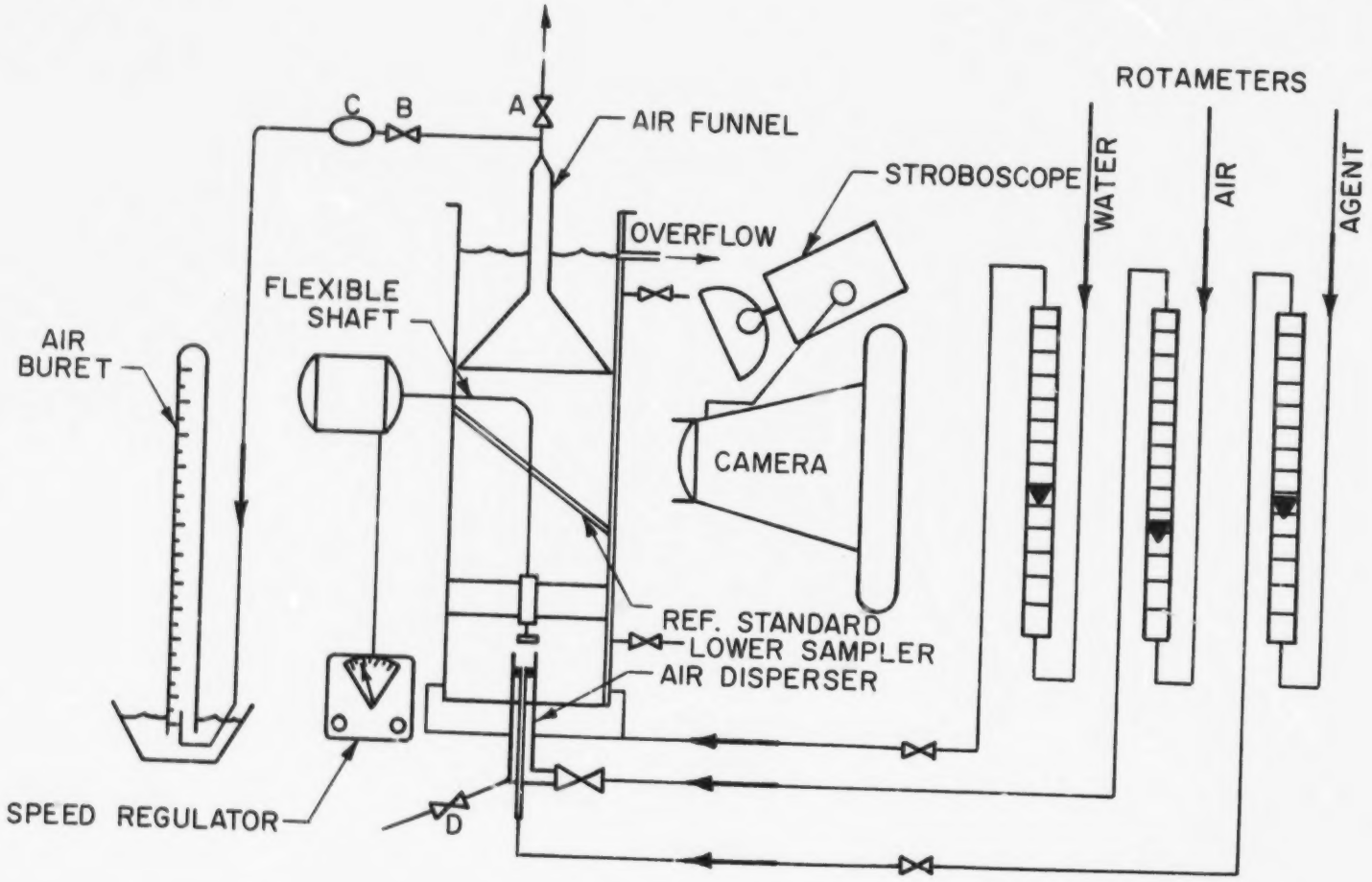

FIG. 4. DIAGRAM OF EQUIPMENT.

by the air, the difference in D.O. concentration between the two sampling points was small and an average was taken (C_b) in computing the results. The D.O. concentration of the water entering the column (C_o) was determined once daily. The changes in D.O. conc. were negligible. The equilibrium D.O. concentration was estimated by averaging the known value at the level of the aerator and the calculated value at the top of the column. The latter was computed from the known depletion of oxygen in the air passing through the column

The Interfacial Area. The surface area of transfer was calculated from the measurements of the gaseous hold-up and the size of the bubbles. The gaseous hold-up was determined by collecting the air under an inverted funnel and measuring its volume in a gas buret. At the end of the test the funnel was lowered into the column and by instantaneous closing of valves E and H and opening of Valve 1 the air collected under the funnel was transferred to the gas buret. As soon as the water in the stem of the funnel reached the level of water in the column, Valve 1 was closed. The air collected in the buret was then measured and corrected for pressure. Usually four hold-up determinations were made and the results averaged.

The size of the bubbles was estimated by means of a photographic technique. A Polaroid camera with a close-up lens was used in taking the pictures. A stroboscope was connected to the camera by means of an electronic flash adapter. A flash of 3 micro-seconds was produced when the shutter was triggered. The film (46-L transparency) was projected and the actual sizes of the bubbles were determined from projection of a standard of a known size. The standard was a metal rod inserted in the column at an angle to the axis of the camera. The advantage of this

arrangement was the ease of focussing, because a part of the standard always appeared in focus and could be compared with bubbles which were also in focus. Usually the major and minor axes of 20 to 30 representative bubbles were taken. This technique was checked by means of glass spheres of known diameter and the error was found to be within $\pm 2.3\%$. Figure 5 shows a picture of the air bubbles and the reference standard.

Figure 5

Photograph of the Bubbles and Reference Standard

The interfacial area was calculated for oblate spheroids from the measured major and minor axes of the bubbles and the gas holdup. First the total number of bubbles was calculated by dividing the holdup by the bubble volume. Subsequent multiplications of the total number of bubbles by the surface area of the spheroid gives the total interfacial area, A:

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$$A = \frac{3H(2 + \frac{1 - \alpha^2}{\alpha} \ln \frac{1 + \alpha}{1 - \alpha})}{4b} \qquad (1)$$

H = Total air hold-up, cm^3

b = Minor semi-axis, cm

a = Major semi-axis, cm

α = Eccentricity = $(1 - (\frac{b}{a})^2)^{\frac{1}{2}}$

A = Total surface area, cm^2

From a series of tests conducted with water, the probable error of each determination was found to be $\pm$ 3.8 cm^2 ($\pm$ 3.5%). In the presence of the substances used in this study the holdup was larger, the bubbles more spherical, and therefore the error connected with this determination was smaller than in pure water.

Calculation of the Mean Transfer Coefficient K_L. The mass transfer coefficient (K_L cm/sec) was calculated from equation:

$$K_L = \frac{10^6 \, q}{A(C_e - C_b)} \qquad (2)$$

where q is the oxygen absorption rate defined by:

$$q = \frac{V(C_f - C_o)}{(60).10^6} \qquad (3)$$

where V is the rate of flow of water in cc/min and C_o, C_e, C_f, and C_b are the respective D.O. concentrations (in ppm) at the inlet at equilibrium, at overflow, and in the bulk of the liquid. Tests conducted in water showed the probable error of a single determinatinn of K_L to be $\pm$ 0.0022 cm/sec ($\pm$ 3.7%).

Discussion of Results. The operating variables investigated in this work were the rate of flow and concentration of the solution entering the aerator and the speed of the disc. The agents used in the tests were n-octanol, 4-methyl-2-pentanol and heptanoic acid. The tests were conducted at a continuous flow and at a bulk concentration of the agent of

one ppm except for two tests in which the bulk concentration was lowered to 0.5 ppm. Since the bulk concentration was constant an increase in the flow rate of the agent was proportional to the decrease in the concentration.

Previous investigations (18) showed that in a similar system, at a constant bulk concentration, different values of oxygen transfer were obtained when concentration of the entering solution was changed. It was also noticed that for a given aerator system and a given bulk concentration there is a certain optimum concentration of the solution at which the rate of transfer reaches a maximum. This behavior can be explained by the fact that at lower rates of flow of the solution (high solute concentration) the solute is not evenly distributed over the air dispersing surface. However, at higher flow rates the uniformity of distribution is improved but the concentration of the solute is less and therefore its effect is smaller. The occurrence of such a maximum could therefore be expected.

In order to compare the effects of the solutes, analogous tests were conducted with water in which, instead of the solute, water was introduced at the aerator at rates the same as those used for solutions. In this way the shearing effect of the incoming solution on the size of the bubbles was eliminated in computing the ratio of oxygen transfer in the presence of the agent $(K_LA)_R$ and that in pure water $(K_LA)_W$.

Figures 6 and 7 give the K_L values for n-octanol, 4-methyl-2-pentanol, and heptanoic acid at different flow rates of solutions and at a bulk concentration of 1 ppm. Figures 8 and 9 present the corresponding values of the instantaneous surface areas.

It can be seen from Figure 6 that when the rotating disc is used an increase in the rate of flow of the solution first causes a drop in the K_L value, which reaches a minimum at about 30 cc/min. It then increases with further increase in the flow rate. Although at the minimum point there

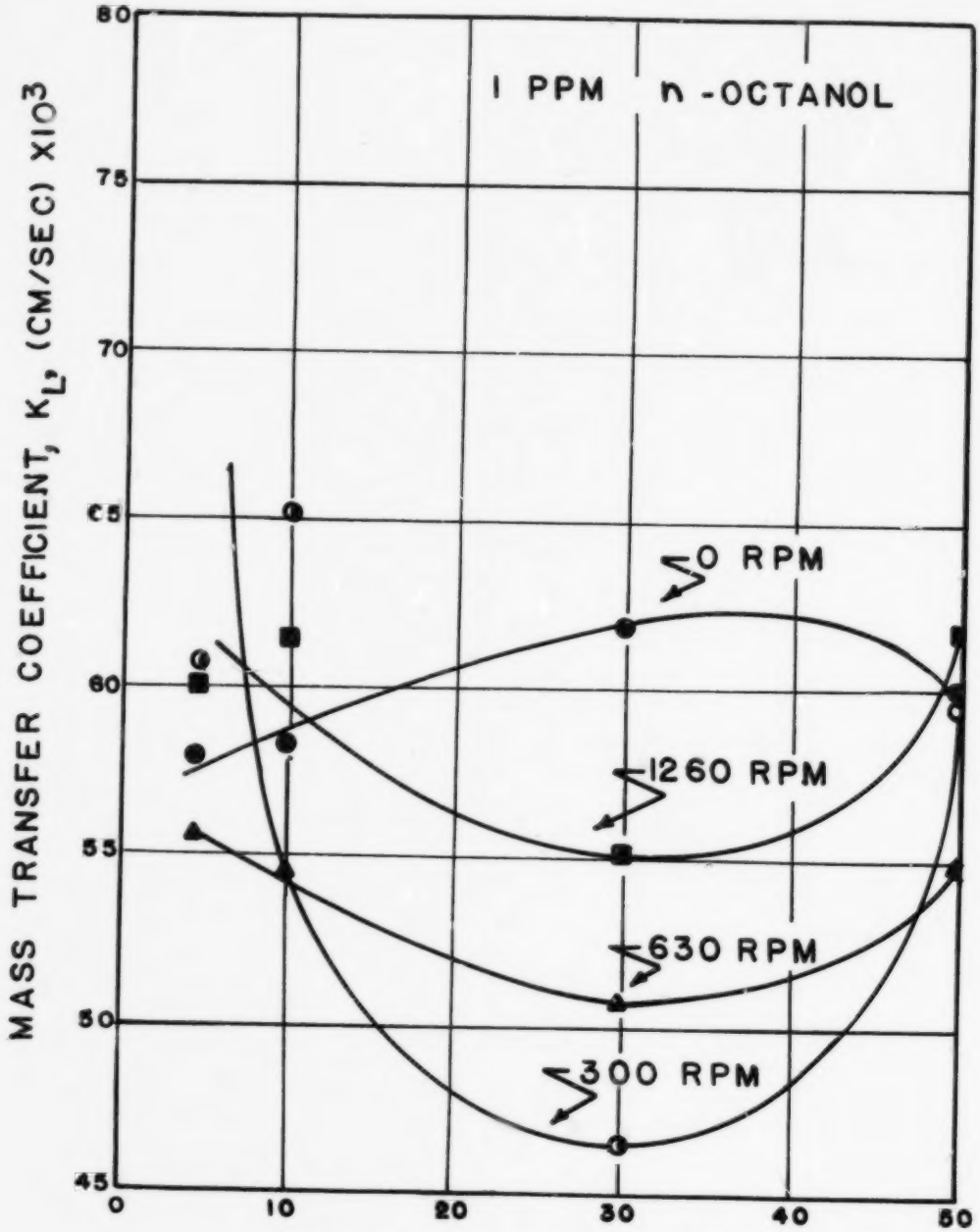

FIGURE 6.

K_L VS. AGENT FLOW RATE

AERATOR WITH COLLAR

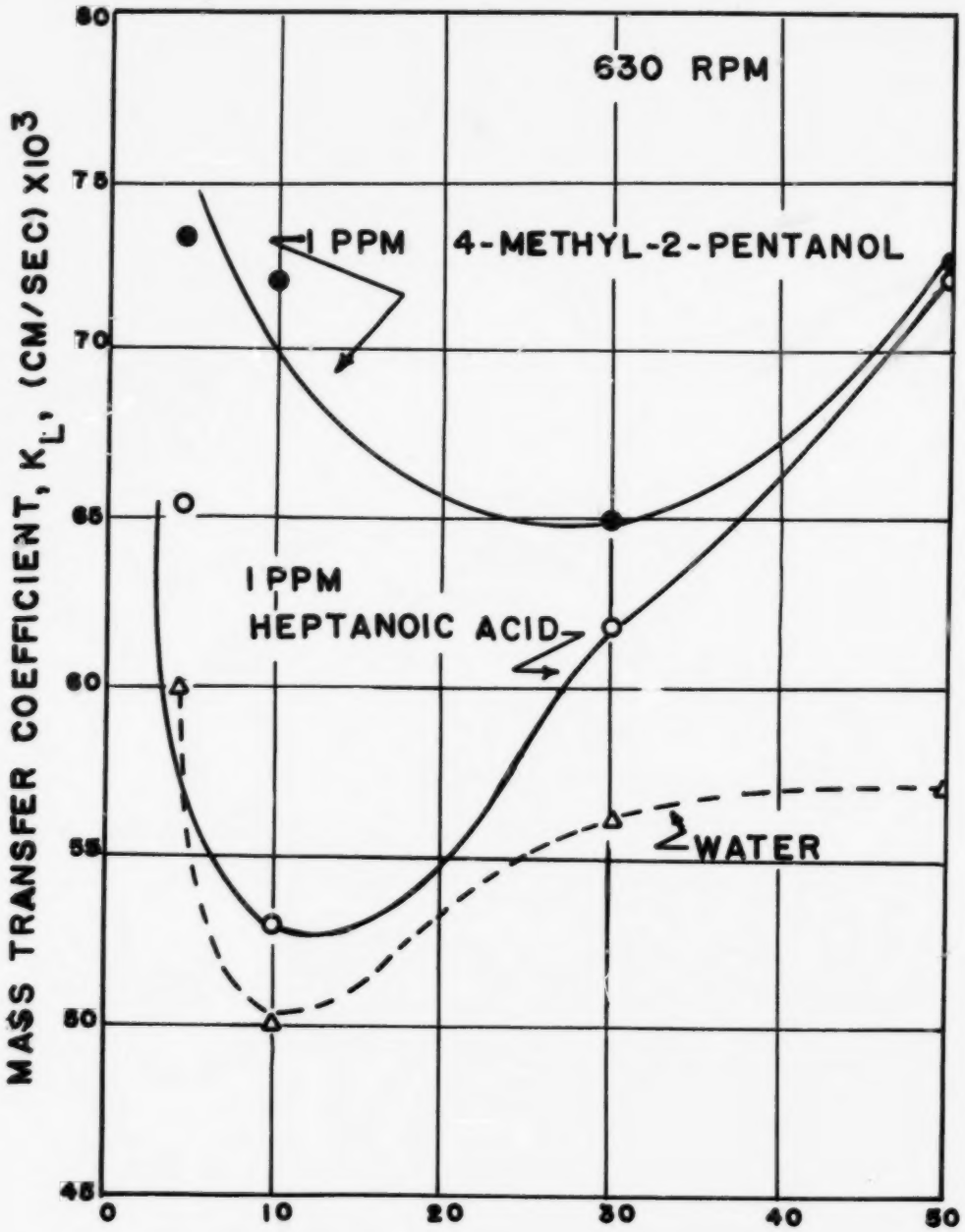

FIGURE 7.

K_L VS. AGENT FLOW RATE

AERATOR WITH COLLAR

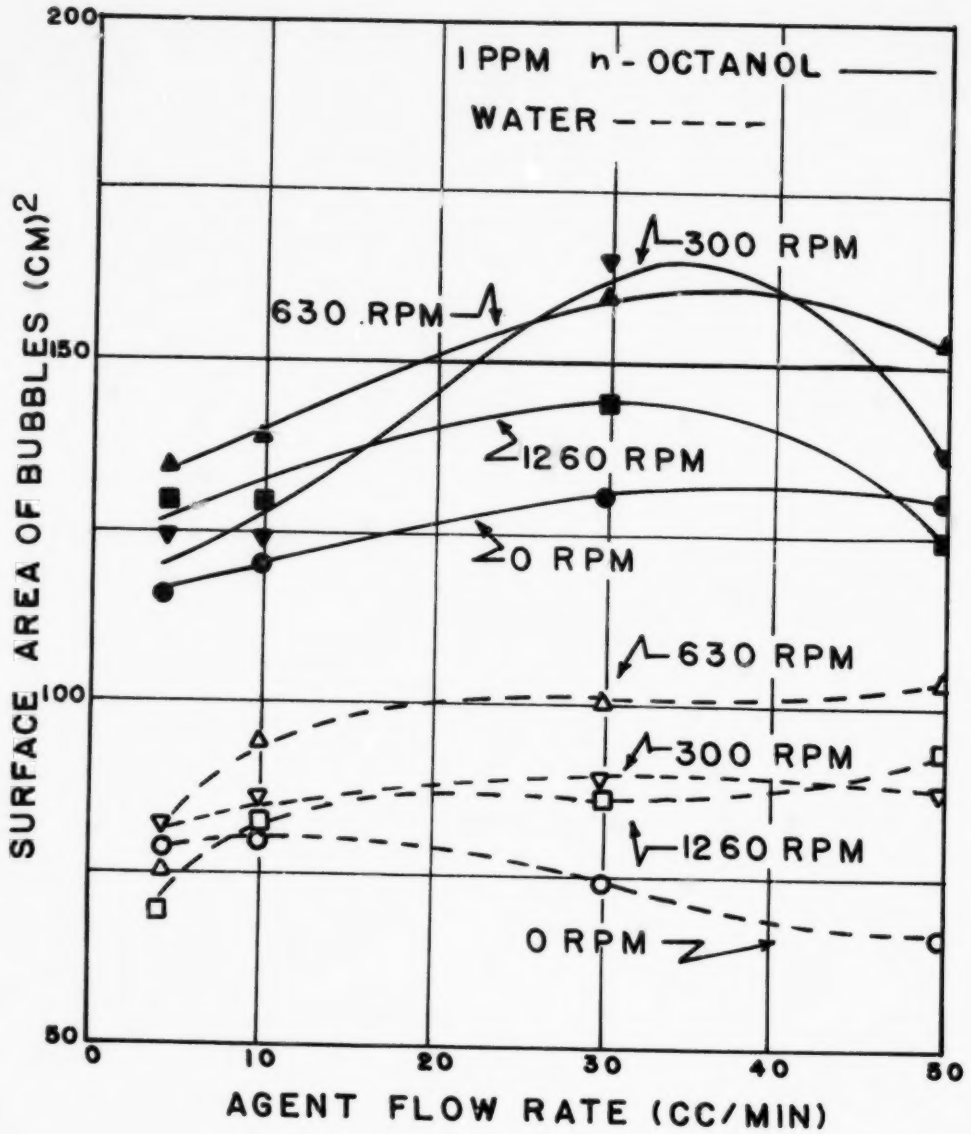

FIGURE 8.
SURFACE AREA OF BUBBLES
VS. AGENT FLOW RATE
AERATOR WITH COLLAR

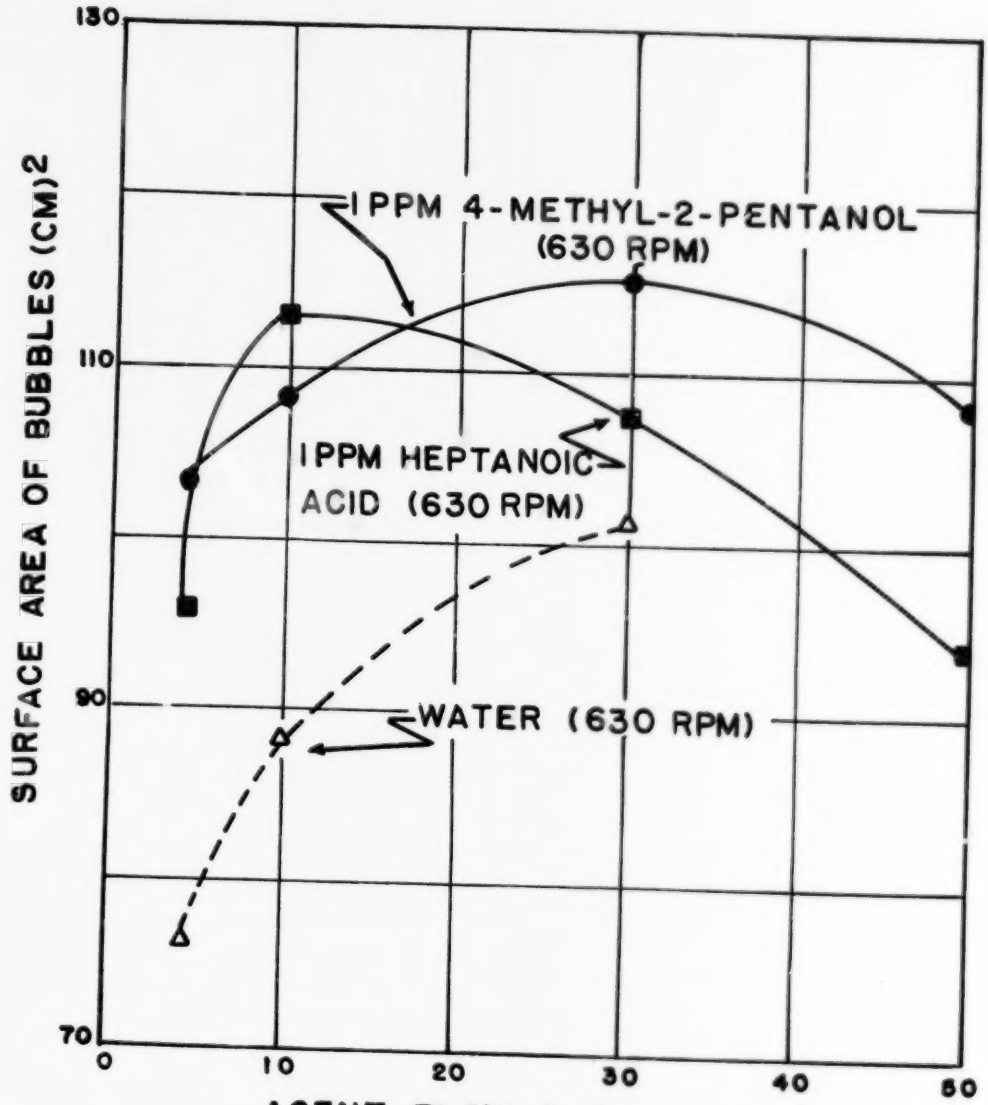

FIGURE 9.
SURFACE AREA OF BUBBLES VS.
AGENT FLOW RATE
AERATOR WITH COLLAR

is a visible trend of a decrease of K_L values with decrease of the speed of the disc, at very low and high flow rates this trend breaks down and there is a considerable scatter of points. Comparing the curve for 630 rpm (Figure 5) with that for water (Figure 7) at the same speed it can be seen that beside some shift in the position of the minimum the K_L value for n-octyl alcohol solution does not differ much from that for pure water. It is of interest to note that for a stationary disc the K_L values appear to increase with the flow rate of the solution reaching a maximum which is in most cases higher than those for the rotating disc.

The curve for 4-methyl-2-pentanol solution at 630 rpm (Figure 7) shows a similar shape as that for octyl alcohol; however, the K_L values are considerably higher than those for water at the same speed. The maximum increase appears at a flow rate of 10cc/min where it is about 40% greater than that for pure water.

The heptanoic acid shows, at low rates of flow, a much smaller effect on K_L; however, at higher flow rates its effect is similar to that of 4-methyl-2-pentanol.

Comparing the effects of the agents on the interfacial surface area of the dispersion (Figure 8 and 9) it can be seen that the curves for the three investigated substances show maxima at the flow rates at which the K_L values reach their minima.

The combined effect of the changes of the mass transfer coefficient and surface area of transfer can be best represented as the ratio of their products for the solution and for the pure water. The magnitude of this effect will be discussed later.

The actual agent concentration in the vicinity of the aerator and its dependence on the flow rate would be difficult to determine. Because of the vigorous convection currents, the concentration is probably not uniform

over the whole air diffusing surface. However, some discussion of the factors affecting the operation of this system seems to be appropriate.

As was mentioned before, for a given bulk concentration, the increase in the flow rate of the solution means a proportional decrease in its concentration. Whereas a higher rate helps in maintaining a more uniform concentration over the surface of the aerator, the lower rate of flow has the advantage of higher agent concentration. Therefore an appearance of a maximum (or minimum) can be intuitively expected both in the case of K_L and surface area values. Photographic techniques (19) indicate that the effect of small quantities of organic substances lie mainly in their action in preventing bubble coalescence. We can imagine that the adsorption and molecular orientation of the polar non polar substances at the interface and the attraction of the polar groups to water (21) decrease the rate of the drainage of the water film separating the bubbles and thus the possibility of their coalescence. It appears that the magnitude of this action should depend, among other factors, on the concentration of the adsorbate molecules at the interface which in turn is a function of their velocities of migration and concentration of the solution. At the very beginning of bubble formation the molecules of the solute start migrating towards the interface. It was found (22) that for a given alcohol the mean migrational velocity ($\frac{cm}{sec}$) is constant and independent of concentration. Therefore, the increase of concentration of the absorbate (g/cm^2) at the interface should increase with concentration of the solute (23). This illustrates the importance of higher solute concentration at the zone of bubble formation as a means of decreasing bubble coalescence and thus producing a larger surface area of transfer. This fact must be combined with the effect of the solute on the circulation in the vicinity of the bubble

interface and therefore on the rate of mass transfer. The molecules of surface active substances adsorbed at the interface decrease circulation and therefore also the rate of mass transfer. This is understandable because in the presence of circulation the tangential velocity does not vanish, and there is therefore a more frequent exchange of the layers of liquid close to the interface. The above was proved experimentally by Hammerton and Garner (28) and mathematically analyzed by Bowman et al. (29, 30).

From this discussion it may appear that the injection of the agent solution while increasing the surface area, affects adversely the mass transfer coefficient. However, tests have shown (Figure 1) that this latter deduction does not apply to a region of very low solute concentration where the K_L value first increases with concentration reaches a maximum and then drops sharply below that for pure water (See Figure 1 and Ref. 19). This may be a possible explanation of the fact that despite the increase of the surface area of transfer in the investigated solutions (Figures 8 and 9) the mass transfer coefficient either remained practically unchanged (Figures 6 and 7) or even increased above that in pure water (Figure 7). This behavior in the region of very dilute solutions is more difficult to explain. It is possible that it is caused by a non-uniform distribution of the adsorbate molecules at the interface resulting in local surface tension gradients which in turn produced a surface disturbance.

The above discussion does not assume that under conditions of the tests a complete monolayer of the adsorbate is formed at the interface. On the contrary the alcohol occupies probably only a fraction of the surface. This is in agreement with the work of Kipling (31) conducted on aqueous butyl alcohol solutions. Franks and Ives (32) also express the

opinion that there is no doubt that alcohols interact with water by hydrogen bonding and that it is possible that at very low concentrations the molecules of the alcohol may be able to "build in" to the water structure. Recently Dunicz (33) showed that alcohol and water tend to aggregate in certain discrete stoichiometric ratios. A better insight of the effect of solutes on the interaction of bubbles in the investigated system can be obtained by estimating the time after which the bubbles come in contact at the surface of the porous plate. From the known values for the air flow, dimensions of the plate and the measured size of bubbles, and assuming a uniform operation of the plate, it is possible to obtain a rough estimate of the time elapsed between the start of the bubble formation and the moment when the bubble reaches its full size and touches the surrounding bubbles. This is the time available for the molecules of the adsorbate to arrive at the surface and protect the bubbles from coalescence when its danger is the greatest. This time was found to be within the range of 0.02 to 0.04 sec. The actual times are probably still shorter because the operation of the plate is never uniform and the convection currents may bring the bubbles in contact before they reach full size. Also, the bubble sizes used in this calculation were obtained in the bulk of the liquid, that is, after partial coalescence. Therefore, it may be assumed that the size of the bubbles at the time of their formation is actually smaller and therefore the available time for the solute transfer is still shorter. It is of interest to compare this time with some of the results obtained by Addison (22) in his studies of dynamic suraace tensions of octyl alcohol solutions. He found that at a concentration of 100 ppm. the time required to reach equilibrium was 0.120 sec. and increased with decreasing concentration.. Tests also showed (35) that in a solution of 4.5 ppm. of decyl alcohol surface tension equilibrium was

not reached before the surface was 60 seconds old. This time is therefore much longer than that available at the plate surface before the first collision of the bubbles. Therefore, it seems justifiable to assume that in most cases the surface tension equilibrium was not reached before the bubbles came in contact for the first time. Since the effectiveness of the solute in decreasing coalescence depends on its concentration at the interface, we may conclude that in this unsteady state the velocity of migration of the solute to the interface is the determining factor. This property depends, among other factors, on the dimensions and polar nature of the solute molecule and on the free energy of the surface (22). This is a possible explanation of the difference in effectiveness of the agents used (19).

It must however be realized that the molecular orientation of the polar-non polar solute should also have a role in affecting the degree of coalescence and the rate of mass transfer from the bubble to the surrounding solution. It appears possible that the degree of molecular orientation and the resulting attraction of the polar groups of the adsorbate molecules to water (21) affects the degree of circulation at the bubble interface and thus the rate of mass transfer. Addison and Litherland found (34,35) by studying decyl alcohol solutions, that even after surface tension equilibrium is reached the orientation of the adsorbed solute still continues until orientation equilibrium is achieved. It appears that this behavior is also a function of the chain length of the alcohols (36).

In concluding this discussion a few words must be said about the rotating disc above the aerator collar. The main reason for the use of the disc was to decrease the inflow of the surrounding liquid to the porous plate and thus the dilution of the agent in the zone of bubble

formation. Although no definite conclusions can be made as to the effect of the speed of the disc, it seems that as far as its effect on the surface area is concerned the lower speed range (300 --630 rpm) is preferable to higher speeds (1260 rpm) or a stationary disc. No further study was conducted in this direction since this would have called for a larger aerator model and investigation of the shapes and dimensions of the rotating element.

The Effect of the Solute on the Total Oxygen Transfer Rate $(K_LA)_R/(K_LA)_W$:

Whereas the determination of the mass transfer coefficient (K_L) and the interfacial surface are of help in better understanding the mass transfer process, their product K_LA is of direct practical value since it refers to the total instantaneous surface area. In addition $(K_LA)_W$ is a result of direct determination based on the known rates of flow and the dissolved oxygen content. A smaller error is therefore attached to its determination than in the determinations for K_L and A.

In order to be able to compare the effectiveness of the investigated substances, the respective $(K_LA)_R$ values in the solution are referred to those in water $(K_LA)_W$ obtained under analogous experimental conditions. In the determination of the $(K_LA)_W$ values water was introduced into the aerator at the same rate as that of the solution used in the actual tests.

The results are presented in Figures 10 and 11. At a bulk concentration of 1 ppm. of n-octanol or 4-methyl-2-pentanol and at a disc speed of 630 rpm the values of $(K_LA)_R/(K_LA)_W$ first increased reaching a maximum at 1.73 at the agent flow of 10 cc/min. Further increase in the flow produces first a sharp drop of the ratio whose value gradually levels off at flow rates above 30cc/min. The curve for heptanoic acid shows a similar

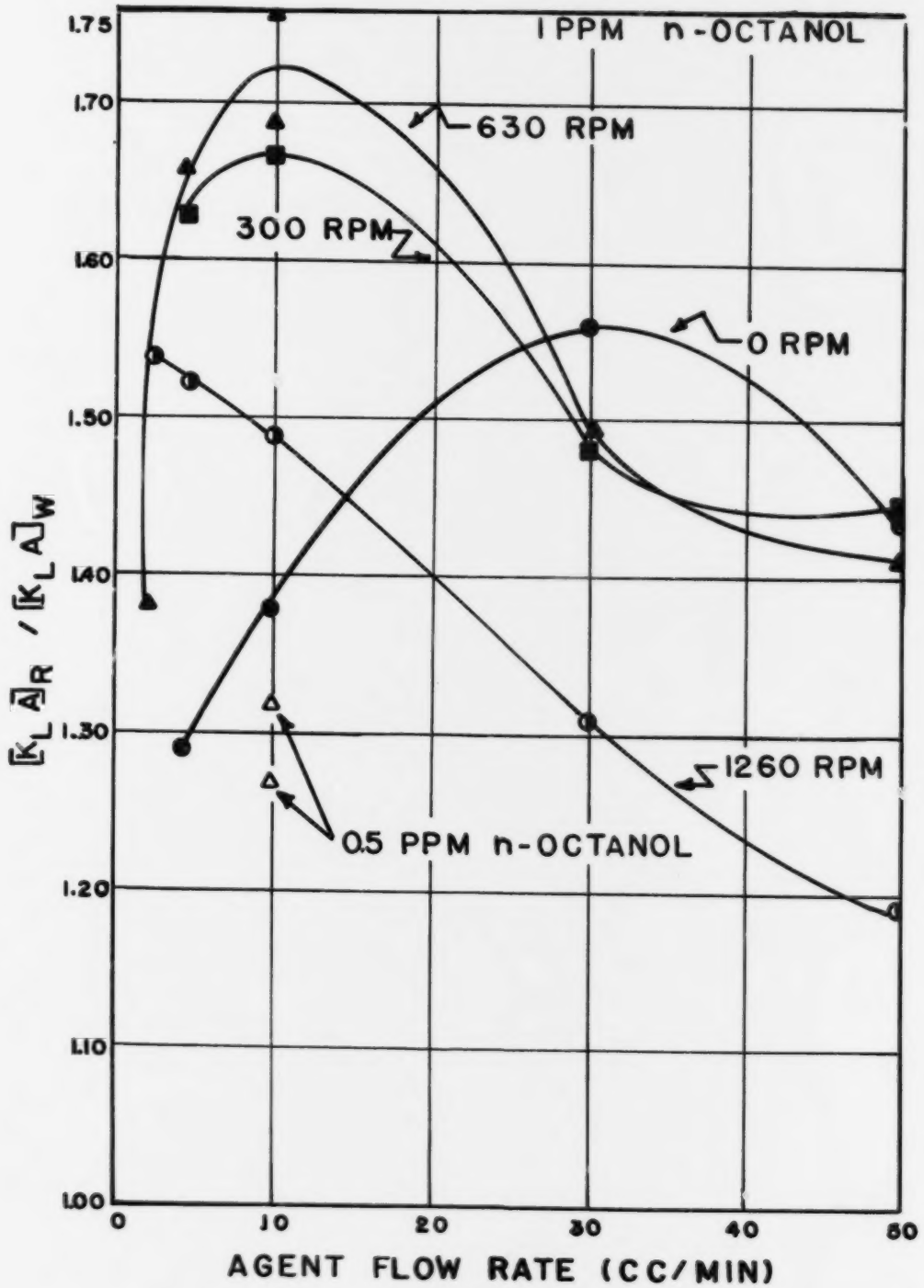

FIGURE 10.

$[K_L A]_R / [K_L A]_W$ VS. AGENT FLOW RATE

AERATOR WITH COLLAR

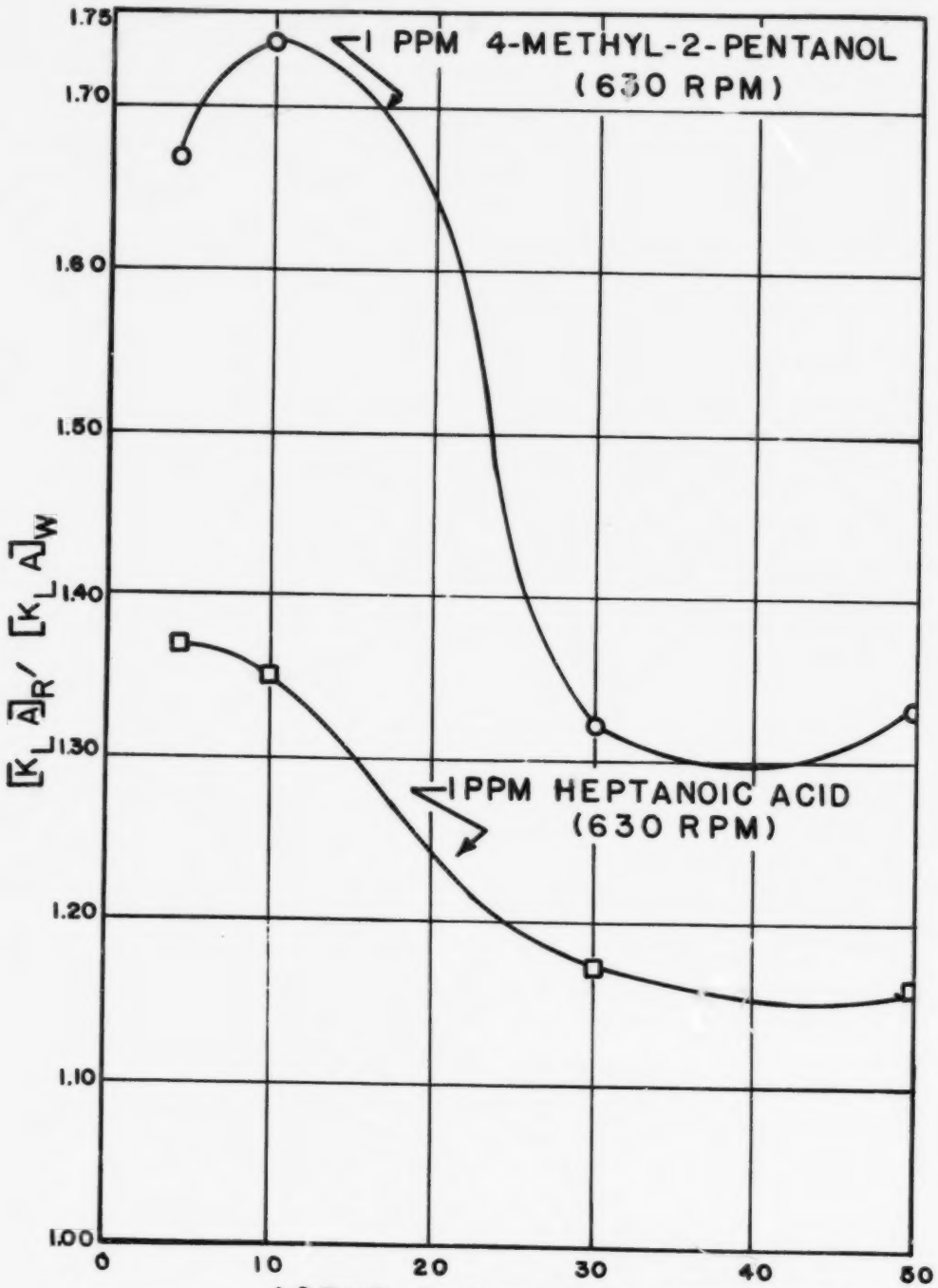

FIGURE 11.

$[K_L A]_R / [K_L A]_W$ VS. AGENT FLOW RATE

AERATOR WITH COLLAR

trend; however, the magnitude of the effect is smaller (Figure 11). It also can be seen that the optimum speed of the disc is somewhere in the range of 300 to 630 rpm. Both the higher speed (1200 rpm) and the stationary disc gave lower values of the ratio.

Probably the most surprising result is the magnitude of this effect. At a concentration of only 1 ppm both the alcohols increased the rate of oxygen transfer by over 70% of that in water. Even at 0.5 ppm, n-octanol gave a rate improvement of about 30% (Figure 10).

In considering these results, it should be realized that no attempt was made to optimize the design or the agent. It can be expected that still better performance could be obtained after optimizing the system.

In conclusion a few important points should be stressed. The aerator used in this work was designed to illustrate the principle of the system and doubtless better and more efficient designs of the aerator could be developed. It is also possible that an agent which is most satisfactory in one system may be objectionable in another and vice versa. It may also be advisable in some processes to take into account the biochemical oxygen demand of the agent, although at the low concentrations used its value probably would be negligible.

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